Hayes. S. P.

COLOR DEFECTS.

[Offprinted from THE PSYCHOLOGICAL BULLETIN, Vol. 23, No. 10, October, 1926.]

COLOR DEFECTS: MEASUREMENT, CLASSIFICATION, HEREDITY

BY SAMUEL P. HAYES
Mount Holyoke College

A large number of articles have appeared since the last review in BULLETIN for 1919, many of which had been printed before that date but were inaccessible because of restrictions during and after the war.

Several writers give descriptions of well known methods of testing color defects. Jennings (65) presents for the guidance of the practical examiner careful directions for giving and scoring a number of tests—the Holmgren Wool Test, the Jennings Self-Recording Color Test, the Williams Lantern Test, the Stilling Plates, the Nagel Card Test and the Nagel Anomaloscope.[1] Titchener (105) advises the use of the Oldberg worsteds authorized by Holmgren as these are more nearly uniform from set to set than many of the collections of wool supplied by other firms. Collins (12) gives explicit directions for giving the Holmgren, Nagel and Stilling tests and the Edridge-Green Lantern Test, and describes various color-naming tests, the use of color equations, contrast effects and negative after-images, the Roaf Painting Test, and a test of color preference by the method of paired comparison. Miss Collins reports the detailed results obtained through the use of her long series of tests with ten color-blind subjects and criticises the tests in the light of their use. Her book will be a great boon to students just entering the maze of color-sense testing. Cowdrick and Winfield (14) give explicit directions for the use of the Hering Color Blind Apparatus, in lieu of the directions supposed to have been prepared by Hering, but not obtainable.

Some extensive surveys of color efficiency have appeared. Franke (32) reports the result of a comparative study in which 750

[1] For the convenience of students of color-vision, practically all the tests mentioned in this review have been listed among the references, with the names of publishers or supply houses and approximate present prices.

subjects were examined with the Nagel Cards, the Stilling Plates, Cohn's Contrast Card and the Nagel Anomaloscope. He finds discordant results with the different tests in 167 cases. On the whole he considers the Nagel Cards and the Stilling Plates most reliable and practical, but advises the use of the Anomaloscope in all doubtful cases. Vierling (**110**) cites extensive statistics to show that if one supplements the Nagel with the Stilling and Cohn tests, very satisfactory results may be obtained. Taylor (**100**) reports the results of 1,000 consecutive tests in the railroad service of New South Wales, using the Holmgren and Stilling tests with the Williams Lantern. The Holmgren and Williams tests are official, but he always uses the Stilling when in doubt, and does not trust the Holmgren when it gives results contradictory to the others. He concludes that any man who passes the lantern test without mistakes and is normal with the Stilling Plates will make a safe engineer. Verrey (**108**) reports the discovery of nearly 6 per cent of color defectives among locomotive engineers who three years before had passed the Holmgren, Nagel and Cohn tests. He used the Stilling Plates first, and then checked up all doubtful cases with the Nagel Anomaloscope. He and Wölfflin (**109**) find that the Anomaloscope gives such delicate measurements that we may soon be able to speak of color defects in quantitative terms such as are now used in reports of visual acuity. He recommends that the Swiss Ophthalmological Society establish normal limits for the equation and pass all candidates who test within these limits. Sulina (**99**) tested 336 children from 1 to 14 years of age, using brightly painted toys with the little children and card tests, wool tests and the Chibret apparatus with the older children. He concludes that the color sense is not developed under two years (15 cases), but that it begins to function and can be demonstrated at two years (29 cases), becoming completely developed between the fourth and the sixth year (53 cases). He found no cases of color blindness among the children over six years in age (239 cases), but reports a slight weakness for green in about 16 per cent of the Russian children and in 18 per cent of the Jewish children. Further reports of surveys are mentioned in the discussion of the heredity of color blindness later in this review.

Critical discussions of the customary methods of testing color vision are numerous. Grow (**39**) finds the Nagel and Stilling tests too difficult for the average examiner to manage and thinks both can be passed by subjects who take the trouble to practice with them. Although he recognizes various deficiencies in the Holmgren test,

he claims that it has been used for 40 years in the U. S. Navy without the occurrence of any serious accident which could be traced to defective color vision. He finds various difficulties with the Jennings test: the examiner may easily make a mistake in putting in the record sheets; bright subjects may memorize it; many normal subjects make mistakes; it does not detect the short-spectrum defectives. He says he has devised a test of his own which cannot be mastered by previous study, but he has not yet published his results. Hunt (63), thinking that the Jennings test involved a type of comprehension often required in certain performance tests of intelligence, made an extended study of recruits and school boys, and correlated the time required in performing the Jennings test with the test scores obtained with the Stearns Group Intelligence Test used with the U. S. Reserve Forces. He found very little relation between the two. Some of the intellectually superior took nearly 4 minutes to complete the Jennings test while some of the feebleminded subjects finished in less than half a minute, " these not being inhibited in the mechanical performance by cerebration. To them green was green and all they had to do was to find green; with those of superior intelligence it was necessary to determine whether there was more green than brown in the olive drab." Boström (5) reports a renewed interest in Sweden through the discovery of a deuteranomalous engineer. He criticises the Holmgren test, the lantern tests and the Nagel Cards, giving his vote for the Stilling Plates and the Nagel Anomaloscope. He recommends that Sweden establish a department for the investigation of doubtful cases. Collins (12) concludes that objective tests, in which the subject does something which may be measured, are much more satisfactory than subjective tests, which depend upon the testimony of the subject concerning his mental experiences of color. Hence she values her contrast and after-image tests mainly for the supplementary evidence they give. As objective tests of great value she cites the Holmgren Wool Test with certain modifications of procedure, her Bradley Paper Test, the Stilling Plates and Part A of the Nagel Card Test. The Edridge-Green Lantern, she thinks, is of the highest practical value. " It has been devised after a long period spent in practical work with color-blinds, and is based on a thorough knowledge of their characteristics. It combines the recognition of colors with the naming of them, which was found to be of great utility throughout the experiments. The modifying glasses are well adapted for the purposes intended, and proved most satisfactory. The test has the

advantage that a short examination with it is sufficient to reveal the defect. Further, it seems impossible to coach a color-blind to pass such a test, so many combinations of colors are possible."

A heated debate has been going on in the German periodicals over the relative values of various well known tests and many new methods for office or clinic use have been described. Oloff (84, 85) tells how the Holmgren and Stilling tests were supplanted by the Nagel Cards and Anomaloscope, which became official and supreme in Germany in 1905. Before the war, however, many criticisms had been published, and when Hess (49) showed that a serious wreck in 1918, involving considerable loss of life, could be traced to the color deficiency of an engineer who had repeatedly passed the Holmgren, Stilling and Nagel tests, the necessity for an improvement in methods was generally conceded. Hess claims that reliable results can never be obtained with the customary methods of office testing, since it is impossible to keep the test conditions constant: colored plates vary in tone and fade with exposure to light; worsteds become soiled; examinations are made under varying conditions of illumination—with blue sky or clouds, in the morning or the afternoon, with reflections from surrounding buildings, from grass, snow, etc. To meet the difficulty, Hess proposes to substitute variable for permanent test colors and to make exact measurements of color deficiency in terms of normal attainment under like conditions. He criticises (58) the use of the Nagel Anomaloscope because it demonstrates only "red-green inequality" and gives no information about the much more important cases in which sensitivity to both red and green is reduced equally. Other writers propose various modifications and improvements of present methods. Just as the Holmgren Wool Test has appeared in various forms intended to be improvements (Cohn, Donders, Magnus, Daae, Oliver, Thompson, Jennings) so now the Stilling test is being revised. The test itself has appeared in a 16th edition under the direction of Hertel (98). Edridge-Green (23) presents a set of 24 cards, 5½ by 6 inches in size, upon which are printed splotches of color in different shades and tints. These splotches all have the same shape and are arranged in the same order on all the cards. The colors chosen are those which defectives of one or other of Edridge-Green's classes ordinarily confuse. The splotches of one color are arranged to form a letter, the splotches of the other color constituting a background. Burch (6) describes a modification of the Stilling test which provides for the substitution of new plates at will. A series of cards, upon which

letters have been painted in confusion colors, is placed in a box and viewed through numerous holes in a screen. By means of a lens the colored letters are put slightly out of focus to obliterate the brush-marks. Ishihara (**64**) offers a convenient booklet of plates formed on the same plan. Each plate is filled with colored circles of different sizes; part of the circles form a letter while the rest form a background in a confusion color. There are 16 plates in all. Great ingenuity has been used in forming them. Plate 1 can be read equally well by normal and defective; in plates 2, 3 and 4, the normal subject sees one numeral, a dichromate another and a totally color-blind subject would not see either numeral; plate 5 is similar, but includes 4 numerals; in plates 6, 7, 8 and 9 normal subjects find a numeral easily, while defectives have great difficulty; in plates 10 and 11, on the other hand, dichromates read easily certain numerals which are difficult for the normal and the totally color-blind; in plates 12 and 13 protanopes read one numeral and deuteranopes another, while normal subjects and incomplete dichromates read both; in plates 14, 15 and 16 lines are substituted for numerals, in order to test illiterates. Clark (**8**) reports the results of a comparative study of the Edridge-Green, Stilling and Ishihara tests. Wölfflin (**122**) describes a modification of the Stilling test along another line. Starting from the claim made by Hess that certain persons are supersensitive to one or another color, he attempts to revise the Stilling Tables by the use of "Umschlagfarben"—colors produced by chemical mixture in such a way that to the normal person they look alike in daylight but are clearly distinguishable in ordinary artificial light, while to the supersensitive they will be distinguishable by daylight, since some colors would appear reddish and others greenish to the supersensitive. Such a test when perfected would diagnose supernormal sensitiveness to one or two colors, and accomplish this much more quickly than is now possible with the color wheel, or the spectroscope.

Podesta (**88**) seeks to avoid the necessity for a multitude of tests by a combination of the best features of the Stilling, Nagel and Cohn tests. He claims three advantages over his predecessors: the plates are large (29 x 39 cm.) and bound so they can be used as wall charts, and for group demonstration; a much greater variety of colors has been used, there being three colored tables on each of the eight large plates; Roman letters have been substituted for the Nagel dots and the Stilling digits. These letters are arranged in such a way that one or more words are visible against a back-

ground of another color. In most of the tables, two words are printed in different colors. Since one word appears in a confusion color, it would be invisible to a color-blind. The other word printed in a darker tone but the same color as the background would appear relatively inconspicuous to the normal subject, but quite prominent to the color-blind who from their childhood have been accustomed to distinguishing colors by differences in brightness. Oloff (86) says, " Podesta's combination and opposition of colors and brightnesses in the same word-picture is a very clever idea. Moreover, those with color defect do not feel so helpless with this as with a test like Stilling's. There is always some word they can read, though it may not be the same one that a normal person would pick out." Oloff has used the Podesta test for years and recommends its use by physicians. Charles (7) commends the Adler Pencil Test because it gives the examiner a definite record of the subject's color confusions. The test material consists of 98 colored pencils. The subject is allowed to experiment with the pencils and then is asked to match the marks he has made with marks made by the examiner who uses standard red, green, blue and yellow pencils. Seydel (97) commends the Helmbold color matching test, after using it with 100 subjects. This apparatus consists of two movable discs 18 cm. in diameter, mounted side by side, each containing a circle of colored dots 6 mm. in diameter around the edge of the disc. The dots are cut from papers of 58 confusion colors selected by reference to the work of Stilling, Nagel, Holmgren, Daae and the author. Over the discs is placed a shield with two holes at the center through which one dot from each disc can be seen at a time. By turning the discs around, any dot may be compared with any other, and the equation recorded by the use of minute numbers printed beside the dots, but visible only when the shield is lifted away. Roaf (91) describes a painting test by means of which he hopes to determine which part of a subject's spectrum is defective. Model paintings consisting of squares divided geometrically into 25 parts each differently colored are laid before the subject, who is requested to duplicate the model by selecting colors from a special box containing 15 pigments. When the subject has finished, the model painting is examined through colored screens which cut out various parts of the spectrum, until a minimum combination of screens is obtained which makes the original look like the subject's copy. A study of the screens used will then reveal the part of the spectrum to which the subject is insensitive. Holth (61) describes a number of simple tests for the discovery of

acquired color defects,—a black wooden cylinder with 3 discs on a side, spaced 3½ cm. apart, and a dark grey cardboard with similar sets of discs, to be used for central scotoma, and a set of cubes of different sizes carrying colored discs, for measuring the color zones. In all his tests he uses the Engelking and Eckstein (**29**) papers which do not change in color tone when seen on different parts of the periphery.

A few tests are now available for use with groups of subjects, and psychologists wishing to make surveys of large classes in order to discover subjects for intensive laboratory work in color deficiency will doubtless be glad to take advantage of them. Many of the Podesta charts can be read as well at 25 feet as at 3, by a normal observer, and if several copies were shown by assistants in different parts of a large lecture room, a good-sized class could be tested quite speedily. Westcott (**116**) has worked out a group test through the use of a colored lantern slide, following the general plan of the Holmgren test. The slide contains three test colors, green, rose and blue, and 40 numbered samples of color selected with the assistance of a spectroscope. Of these 10 are green, 5 rose, 5 red and the remainder confusion colors in blues, browns and greys. In giving the test, the colors are projected upon a screen and the class is asked to make a list, by number, of all the colors which resemble color A (Green). These lists are signed and collected and the test is repeated for B (Rose) and later for C (Red). Hess (**48**) reports that if small red and green discs are combined on a color wheel to match large discs of yellowish grey and shown to a large group, some will see the inner circle as reddish and some as greenish. By asking for a written report, anomalous cases may be located.

Two writers think that color-blindness shows itself in the face. Taylor (**101**) reaffirms his belief that color defect is often indicated by changes in the face, voice and general behavior, and suggests that this knowledge may be an aid in detecting cases. He claims that the tone-deaf react in a similar fashion, and assumes a close association between color sense, musical sense and moral sense. He believes that color-blindness and tone-deafness are both degenerative conditions. Wirth (**118**) finds the color-blind very likely to show a hectic redness of the cheeks. He has noted this characteristic in many of his cases and quotes Kirschmann as holding a similar view. In the 34 cases studied he finds a correlation of .66 between color-blindness and abnormal facial coloring, and raises the question

whether both traits may not be symptoms of general constitutional weakness.

Of conspicuous importance, especially in the laboratory study of doubtful cases, are the new methods described and demonstrated by Hess in a series of articles, culminating in an extended review (58) of the work on color vision during the last 20 years, in which 194 articles are considered. Since we cannot depend upon the results obtained by the use of pigments, Hess (49) undertakes to invent types of apparatus which will permit the continuous variation of the color and brightness of the stimulus, without the use of costly spectral apparatus or time-consuming tests with rotating discs. He has perfected three types of "Farbensinnprüfer," in all of which color mixtures are obtained through the use of the Goldberg wedge-shaped color filters. His "Modell für die Praxis," he says, meets all the demands made of a practical color test—that it should give a sure diagnosis, make possible the examination of large numbers of subjects without loss of time, be cheap, and not be too difficult for subject or examiner. The subject is asked to look at a transparent spot of oil paper, 1 cm. in diameter, at the center of a dull white card. The spot is illuminated by an electric light inside the apparatus, which sends its rays through color filters. To test for inequalities in sensitivity for red and green, blue and yellow filters are combined to produce green, and a mixture of red and grey is reflected upon the green by means of a movable mirror. By changing the proportions of the different colors, the spot may be made colorless to the normal eye, and by moving the apparatus toward or away from the source of external light, the ground may be equated with the spot in brightness. The subject is then asked what color he sees, and classed as deuteranomalous if he calls the spot red, protanomalous if he calls it green. This test may be confirmed by changing the relations of the color filters till the spot appears colorless to the subject and recording its appearance to the normal subject. To test for color-blindness, the red light is turned off and the blue and yellow wedges moved so as to produce a series of colors from yellow-green through green to blue-green, equating spot and background in brightness by moving the apparatus as before. The subject is asked to name the colors, and his statements recorded with those of a normal subject observing the spot at the same time. Generally dichromates call the yellowish-green yellow, and the bluish-green blue. Hess cites as additional advantages, the facts that tests may be made either in natural or in artificial light and that

subject and examiner can both see the changes in color and brightness at the same time, instead of being obliged to look successively into a tube. Hess has a somewhat more elaborate "Klinisches Modell" which uses reflected light in much the same way as in the Hering Color Testing Apparatus. This model may also be used to chart the color zones of the eye and to determine the color thresholds. His "Tunnel Modell" yields exact measurements, in terms of the distance one must move the light which illuminates the red filter. Hess claims the following advantages over the Nagel Anomaloscope: exact equations are obtainable; only the red is changed while in the anomaloscope both red and green are changed; only the intensity of the red is changed while in the anomaloscope the vibration rates of both red and green are changed; not merely the fact, but also the degree of color defect is determined; the apparatus is easily and quickly handled. The use of color filters for the exact measurement of color defect is recommended also by Ferree and Rand (33), Rochat (93) and Hegner (42).

In a later article Hess (55) describes an apparatus which attains much the same results as his first two models, but with the use of color discs in place of color filters. His discs are cut on a curve from center to periphery so that for each mm. on the radius there is one more degree of curvature. In front of the color wheel he mounts a grey screen with a hole in the center, and in front of this a still larger screen pierced by a tube. The screens and tube are movable right and left, so that a position may be found in which the mixture seen through the tube and the screen matches the screen in color, and this screen can be rotated on a vertical axis so that it will reflect just enough light to match in brightness the mixture on the color wheel.

The "Differential-Pupilloskop" makes possible still further measurements which Hess (50) considers extremely important in the diagnosis of acquired as well as of congenital color defects. From his extensive studies of the color vision of man and animals, Hess drew the conclusion that in the eye our sensory and motor receptors are identical. In the middle of the retina stimulations which are sensed as colors are accompanied by the ability to change the size of the pupil, and this ability decreases from center to periphery. If two lights of unequal intensity play upon the eye in rapid succession the pupils become narrower with the strong and wider with the weak light. With two lights of different color but equal brightness, the pupils remain unchanged. In total color-

blindness these pupillary changes do not occur, and in partial color defects a loss of color sensitivity is accompanied by a loss of pupillary change for the color chiefly involved, while there may be a greater response to other colors. Protanopes and protanomalous trichromates show a lower motor value for red and a higher than normal value for blue; deuteranopes show about normal values for red and blue; deuteranomalous trichromates often show a supernormal motor response for red. Engelking (**30**) and Groethuysen (**38**) report favorably upon the use of the Pupilloskop, Groethuysen having made thousands of measurements with it.

Several important studies of color defectives have been published. Collins (**12**) reports in detail the careful examination of ten dichromates by a long series of tests. The primary object of her investigation was a critical study of the value of various methods of testing color vision, but the psychological question of the sensations experienced by color defectives soon became the central interest. Her work is peculiarly uninfluenced by questions of theory. Her main conclusions may be briefly summarized. (1) Dichromates vary enormously in their sensitivity to red and green. (2) Besides the well known neutral zone in the blue-green region, dichromates have a second neutral zone in the extraspectral purple which for us is complementary to green. (3) Dichromates are especially sensitive to contrast effects and show very rapid color fatigue. (4) A modification in the intensity of light is for dichromates equivalent to a change in color. (5) Dichromates do not guess at colors, as has often been supposed, but try to use our color names for a fairly constant color system different from ours, even such apparently meaningless terms as "reddish-green" and "greenish-red" being used with such consistency that they seem to describe a true color experience. (6) Color-blindness is so common and makes such an important vocational handicap when present that it seems wise to institute a systematic examination of all children before they leave school. Reichert (**89**), whose right eye is considered deuteranopic while his left is normal, reports the results of naming spectral colors and making equations with rotating discs, using the eyes separately. He seems to have a typical full-length dichromatic spectrum with a neutral zone in the blue-green region. Roenne (**94**) reports a study of incompletely color-blind persons with equations on rotating discs in which green plus black were made to match green plus red plus blue-violet. Determining in each case the size of the purple sector which his subjects could not distinguish, he concludes

that Köllner is right in claiming that dichromates and anomalous trichromates are linked through transition forms and suggests that dichromates may be considered as "reduction forms" from the anomalous rather than from the normal, as Von Kries suggested. Köllner (71) describes an extended study of the Rayleigh equations of anomalous trichromates which he undertook to determine whether they may be regarded as transition forms between the normal and the color-blind. He concludes that the Rayleigh equation of this group can be explained only by assuming a change in the color value of red and green light. The deuteranope sees both red and green as shades of yellow. The deuteranomalous trichromate has not lost quite so much and the green has suffered more than the red. The protanomalous trichromate also shows more uncertainty with green than with red, but is chiefly distinguished from the deuteranomalous by the greatly reduced brightness values of colors. The deuteranomalous equation may be changed into the protanomalous by the use of absorption glasses which reduce the brightness of the red and yellow lights.

The question of heightened contrast among anomalous cases has had considerable attention. It will be remembered that Guttmann made much of this in his early reports of experiments upon his own color vision, and he still assumes the fact in a recent article (40) in which he attempts to prove that the heightened contrast of the anomalous is due to retinal rather than central factors. His method consists in presenting patterns calculated to produce contrast colors to a single eye in the ordinary way, and to the two eyes by means of a stereoscope so arranged that the inducing color and the grey field on which a contrast color might appear are presented to different eyes. By the monocular method he finds the usual heightened contrast, but with the binocular method his anomalous trichromates experience less contrast than normal subjects. He concludes that the heightened contrast is a retinal phenomenon, as it does not arise when the two eyes are stimulated differently. Nagel was so convinced of the importance of heightened contrast in anomalous cases that he constructed some of his cards to take advantage of it, the expectation being that a yellowish dot next to a red one would look green, a grey dot between green dots pink, etc. Nagel claimed that a contrast color might appear on rotating discs, when the inducing color was still subliminal. Grill (37) reports the results of a comparative study of a normal and an anomalous subject using Göthlin's anomaloscope. A monochromatic light was shown in half the field

and a neutral light of equal brightness in the other half. With red the contrast effect was decidedly more marked, with green decidedly less marked, for the anomalous than for the normal observer. With blues and yellows no difference between the two subjects was noted. Lohmann (**76**) attempts to determine whether contrast is a factor in forming the Rayleigh equation (red plus green equals yellow) in the Nagel Anomaloscope. He arranged the apparatus so the spectral yellow and the red-green mixture could be presented successively and thus not influence each other. With this arrangement most of his anomalous subjects accepted the normal red-green mixture. Further experiments with a Lummer-Brodhun photometer convinced Lohmann (**77**) that it is fair to attribute heightened contrast to anomalous trichromates. Köllner (**70**) seeks an explanation of this heightened contrast. Repeating Guttmann's experiments with rotating discs, he reports clear evidence of heightened contrast. He obtains similar results with colored lights. He does not find, however, that the anomalous get contrast from a lower saturation of the inducing color, as has been claimed. In fact, with rotating discs the contrast threshold is higher for the anomalous, a fact which explains their failure to see contrast colors with the Hering window and the Cohn tissue paper test. Köllner attempts an explanation on the hypothesis that color weakness is due to peripheral changes, while contrast is due to central changes. Ordinary objective colors are seen much less vividly by the anomalous, so contrast colors, which are subjective, become overvalued in comparison with the objective colors. The heightened contrast is thus the result of a false judgment, and does not form an exception to the generally conceded lower color sensitivity of the anomalous. Hess (**55**) thinks it a mistake to speak of heightened contrast and attempts an explanation of the facts in terms of his discovery of red-green inequality rather than color weakness in the anomalous group. For them the purity of colors is different from that of normal subjects. The protanomalous, for example, see green purer than normal, while their yellows and blues are mixed with grey. There are also decided differences in brightness. These conditions might have a great influence upon the perception of contrast colors. Guttmann (**41**) reports upon a study of after-images made in 1909 but delayed by the war. He had previously discovered that his anomalous subjects got the same after-images as dichromates, the red-yellow-green part of the spectrum giving a blue after-image and the blue-violet end giving a yellow after-image. He now finds that the after-images of his

anomalous subjects last only about 2/3 as long as those reported by normal subjects, and suggests as an explanation the quickness of fatigue to color characteristic of the group.

Several brief reports of experiments upon totally color-blind subjects have appeared. Bender (3) used 9 normal subjects and two typical achromates in a study of the luminosity of spectral colors, using a Lummer-Pring spectral flicker photometer. His two abnormal subjects were not only totally color-blind, but had low visual acuity and light-dread. In both cases the place of maximal brightness fell in the blue-green region at about 515 mm. Velter (107) reports a case with a light red unpigmented zone in the macula of each eye. Hofman and Nussbaum (59) report three cases, one lacking macular adaptation completely, and one showing normal macular adaptation in one eye and none in the other. The authors claim that the macular functioning of the totally color-blind eye follows no definite rule either in bright or in dark adaptation and cannot be used in deciding debated questions of color theory. Wernicke (115) reports two cases, brothers, with only about 1/10 vision, light-dread and vertical nystagmus. Crosland (15) reports experiments upon a totally color-blind subject with myopia, astigmatism and strabismus of the right, weaker eye, but makes no mention of light-dread or nystagmus. In sorting wools and comparing them with a set of 50 Hering greys, the subject tended to put the yellows into the lighter groups and the greens and blues into the darker groups, thus failing to show the Purkinje phenomenon. Hess (58) claims that he does not find foveal blindness in the totally color-blind, that his cases do not become blind in a bright light but close their eye-lids part way to see better, and that various phenomena occur in light and dark adaptation which are not readily explained on the Von Kries hypothesis that the totally color-blind are "rod-seers." Engelking (30) reports upon a special study of eye-motor reactions under various conditions of light adaptation. Flash light pictures of the totally color-blind show certain characteristic positions of the lids and the eye-balls under stimulation with different colors, the lids being nearly shut and the eyes turned upward in response to bright grey or yellow-green, the lids half-shut and the eyes half-exposed with dark grey or blue, and the lids fully open and the full eye showing with black and red. The width of the pupil varied similarly according to the brightness of the stimulus color, giving motor values in the Hess Differential Pupilloskop which form the extremes of a series including normal, protanomalous, protanope and totally color-

blind. In adaptation the totally color-blind react very differently from the other types, however. After dark adaptation the pupils of the totally color-blind react to strong light as much, though more slowly than the normal; after bright adaptation followed by dark adaptation, the pupils of the totally color-blind open much more slowly than do the normal and the partially color-blind. All the other types react in much the same way, leaving the totally color-blind in a class by themselves—a fact which may perhaps be explained on the duplicity theory according to which the totally color-blind have only a twilight apparatus which adapts itself much more slowly than the daylight apparatus to changes in illumination.

Robinson (90) gives a detailed report of experiments with Holmgren wools, Hering colored papers, the Nagel Cards and spectral lights with a blue-yellow blind subject concerning whom she had published a brief account ten years before. She gives abundant evidence for her general conclusions: that this subject is insensitive to blue and yellow as colors, while showing fair sensitivity to red and weak sensitivity to green; that his spectrum is not shortened and has its maximum brightness in the colorless blue region; that his color defect has a congenital basis.

It has often been reported that intelligent color defectives learn to take advantage of secondary criteria in distinguishing colors. Robinson (90) reports that her blue-yellow blind subject noted what he called texture, flatness or smoothness of surface, shade, brilliance, or dullness, and mixture. She had as much difficulty in understanding what these terms meant to him as he had in understanding what blue and yellow were, as colors, to her. Colored or uncolored surfaces, he said, had a texture that grey surfaces lacked. Uncolored surfaces were not well-mixed and flat as were grey surfaces. Orange was a particularly unmixed surface. A mixture containing red was darker in shade than green when both were subliminal, and this shade was sometimes the basis for distinguishing green. Blue was brilliant in surface—had a glint to it—while yellow was dull. Purple and violet were both described as being " thin reds " with the luster that characterizes some blue surfaces. With the help of these secondary criteria he concealed his color-blindness from his friends and even from his students when he was teaching physics in a small high school. A curious illustration of the skill used in following secondary criteria is given in the case reported by Gildemeister and Dieter. (35) An engineer rejected in 1910 because of uncertainty with the Nagel Cards was later examined several times with the

Nagel and Holmgren tests and passed, though the anomaloscope classified him as a typical protanomalous trichromate in 1914. He was further examined with varying results until 1919 when he made no mistakes with colored objects and showed great improvement with the anomaloscope. Since it seemed unlikely that his color sense had improved, tricks were suspected. Could he help himself out by muscle memories? Had he learned, perhaps, that if he turned to a full stop and then went back a certain distance, his equation would be accepted? To get an answer to such questions, the anomaloscope was turned upside down and the knobs adjusted to move in the opposite direction. But he still succeeded with the equation. The authors then concluded that the subject had learned to accept an equation which looked wrong to him, and this assumption was checked up by experiments upon one of the writers who was a deuteranomalous trichromate. This subject was put through a series of daily practice tests and soon learned to pass the test by recognizing and accepting the normal equation although it always seemed wrong to him. And he retained this ability after several weeks without practice during the interval. Kirschmann (68) and Roaf (92) suggest that by the use of colored glasses or screens slight differences in the sensations caused by colors generally confused may be brought to the attention of color defectives and that by practice they may be taught to distinguish these colors without help.

A few cases of acquired color-blindness are described. Atkinson (2) reports observations on snow-blindness in the Antarctic and in Europe, comparing it with the effects of telescopic observations of the sun and the use of the eyes in watching welding operations with high power electric currents. Lohmann (75) reports experiments upon two cases of red-green blindness following snow-blinding. Edridge-Green (25) tells us that a man recovering from influenza developed red-green blindness which disappeared after five months. Boehmig (4) reports color disturbances after strenuous physical exercise sometimes causing central scotoma, which lasts as long as twenty hours in extreme cases. He assumes a pathological activity of fatigue poisons upon the pupillary macular nerve bundle. Wölfflin (119) finds that by the use of caffein and strychnine the threshold for red may be lowered for deuteranomalous trichromates, while sensitivity to green, yellow and blue remains unchanged. In two deuteranopes the sensitivity to yellow was distinctly raised. He used and commends Engelking's "peripheriegleichen Farben"—colors of equal brightness and saturation which show no color changes

in passing from periphery to fovea. Engelking (27) reports the successful use of these colors in the study of the gradual constriction of the color zones in acquired color defects. Eliot (26) reviews a number of cases in which alterations in color perception and in color fields followed quinine poisoning.

The question of the classification of color defects is engaging the attention of many students. Troland (106) sums up the general state of affairs. "There appears to be a great deal of uncertainty at the present time regarding the exact number of congenital forms of color-blindness, and it is to be hoped that some careful student will undertake to sift out the really characteristic types, to evaluate the evidence for and against their hereditary origin, and to determine their statistical relationships to fluctuations in the normal type. . . . It is obvious that the original restriction of color-blind types to protanopes, deuteranopes and tritanopes is no longer adequate, and we must make allowances in our color theories for more types of variation than are indicated by primitive considerations concerning the visual mechanism." Allen (1) attempts a classification based directly on the Helmholtz theory. Since we have proved the fundamental sensations to be red, green and violet, he says, there must be seven main types of color-blindness, three with one color missing, three with two colors missing and one with all three colors missing. Edridge-Green (20) feels equally sure of quite a different classification into seven types based upon his records of the number of distinct colors which can be seen in the spectrum. Hess (58) has made a serious attempt to determine, by the use of new and improved methods, the exact differences in color sensation experienced by various color defectives, aiming to measure the degree of color defect as exactly as we can now measure degree of visual acuity. He presents the following classification: Subjects may be slightly over- or under-sensitive to any color and still belong to the "normal" group. Hess quotes the case of an eye specialist who had long been a railroad examiner. This man was over-sensitive to red with normal sensitivity to green, and this red-green inequality showed itself in several tests. He could not pass the Stilling test and in the Nagel Anomaloscope the normal equation looked very red. He reported that during the war he was able to recognize colored enemy fireworks better than his associate officers. In a spectral test he could see beyond the normal limits for red. Another subject showed extremely high sensitivity for green. Hess thinks that many anomalous cases have been wrongly classed as color-weak because they do not accept the normal

Rayleigh equation, when all that this proves is color inequality, which may result from supernormal sensitivity to one color. But there are also cases in which normal sensitiveness to one color is associated with subnormal sensitiveness to the other. Hess would call these subjects red-sighted and green-sighted, preferring these terms to the customary deuteranomalous and protanomalous since these are based on a three color theory and carry incorrect connotations. The red-sighted require less red than the normal subject in the Rayleigh equation, have a wider than normal field for red and a narrower than normal field for green, and show higher than normal motor values for red. Their sensitiveness to blue and yellow is about normal. The green-sighted require less green in the Rayleigh equation, have a wider than normal field for green and a narrower than normal field for red, and lower than normal motor values for red. Their blue and yellow zones are generally constricted but they sometimes have higher than normal motor values for blue. For the two classes of dichromates, Hess prefers the names red-blind and green-blind, as the special deficiency of one color is the primary characteristic. The green-blind suffer a less serious disorder than the red-blind; although unable to see either red or green, their threshold for blue and yellow is equal to normal and their blue-yellow zone equal or superior to normal. Their motor values for red and blue are generally normal. The red-blind approximate the totally color-blind in various respects. Their threshold for blue and yellow is raised, their blue-yellow zone is constricted, their motor values for red are low and for blue higher as in total color-blindness, and they have a shortened spectrum with displacement of maximal brightness to the blue-green region. Hess cites six lines of evidence indicating that the red-blind are relatively under-sensitive to blue and yellow, like a dark adapted green-blind and occupy an intermediate position between the green-blind and the totally color-blind.

The wide diversity of opinion upon the question of the classification of color defectives may be partly explained on the basis of rival color theories; but a second factor of great importance is the enormous individual differences in the subjects studied, making it seem almost equally reasonable to class some subjects in either of two groups. An excellent example of the range of individual variation may be found in the tables presented by Franke (32), in which are included the Rayleigh equation readings in the Nagel Anomaloscope for twenty-seven doubtful cases and for twelve anomalous trichromates. Malling (79), using a Helmholtz color-mixture apparatus,

tells the same story. He finds some departure from normal sensitiveness in a large per cent of his subjects and surmises that sooner or later it may be possible to show a complete series of transition forms from the normal through all types of color defect to complete color-blindness. His chart showing the variation in position and breadth of the neutral zone in a series of cases, points definitely toward such a result. Collins (12) finds individual variations in all her different tests and gives the results in an illuminating comparative table of her ten dichromates tested in twelve different ways. After an unsuccessful attempt to picture her cases in diagrammatic form she concludes that so many individual types exist that "it is unprofitable to try to systematize the color sensations of the color-blind." Hess (58) constantly emphasizes the wide variations in sensitivity not only to red and green but also to blue and yellow, and cites numerous cases in which sensitiveness to one color or to a pair of colors varies independently of sensitiveness to the rest. Within each group cases may not be closely alike, so it is dangerous to generalize from one or two cases which may not be representative. Between types he finds transition forms which are not easily classed in either group. Hess (56) marshals five distinct lines of experimental evidence to prove the existence of transition forms between partial and total color-blindness. One wonders if we shall presently have to give up all classification by types, arrange color defectives in distribution tables and give a color graph or profile for each subject showing his efficiency or deficiency for each color in terms of a per cent of the normal or average attainment. Engelking (31) agrees with Hess in claiming that deuteranopes and protanopes are radically different and that protanopes share certain deficiencies with the totally color-blind. But he finds a marked difference in the brightness curves of the last two groups, and notes other peculiarities of the totally color-blind which are not found in protanopes, such as reduced visual acuity, slower widening of the pupil with reduced lighting and a lower fusion frequency. Köllner (72) supports Hess in his classification and in his conclusion that the normal green-blind, red-blind and totally color-blind form a definite evolutionary series of progressively more serious color defects, but with no transition forms between the green-blind and the red-blind. The anomalous groups give the greatest difficulty to the practical examiner and the emphasis Hess puts on red-green equality and inequality points to a solution; for while the anomaloscope detects those with red-green inequality it fails to discover those who are equally insensitive to red and green.

Such subjects may be as dangerous as dichromates and some further method must be used to keep them out of service where color discrimination must be normal. Von Kries (74) finds the review Hess makes of the last twenty years of progress in the study of color vision so one-sided and erroneous that he cannot let it pass without protest. He publishes an extended treatment of the whole subject of color vision from the point of view of the duplicity theory. Oloff (86) takes up the cudgels in defense of Hess especially on the question of practical color testing. He gives an interesting historical review of the rise and fall of the Nagel methods. Oloff thinks diagnosis is not possible with pigment tests. For preliminary surveys he still values the Stilling, Nagel and Cohn tests and thinks very highly of Podesta's Tables but insists on the use of the anomaloscope in all doubtful cases. While greatly impressed with the new equation methods devised by Hess, he does not approve of their general introduction until after a long period of trial. Candidates should not suffer from further defective methods!

The heredity of color defects has engaged the attention of various writers. Cole (11) gives genealogies for some old cases and Vogt (112) for some new ones. Several other writers have made important contributions involving extensive collections of published genealogies and the presentation of elaborate new ones in which all accessible members have been carefully tested by approved methods and the results interpreted with reference to the biological laws of heredity. Schiötz (95) reports upon a survey in which about 3,000 school boys, recruits and railroad men and over 2,200 school girls were tested. He used a battery of tests including the Holmgren and Daae wool tests, the Cohn contrast card, the Nagel Cards, the Stilling, Ishihara and Podesta Tables and the Nagel Anomaloscope. He claims to have tested 500 color-blind men and 40 color-blind women in the course of his work. After a review of the published genealogies and a comparison of these with his own, he concludes that "if we assume that color-blindness is a recessive character in Mendel's sense, and that the gene for color-blindness is carried by the sex chromosome, then every obscure feature of its inheritance becomes perfectly clear." Vogt and Kleinguti (113) report upon a systematic study of the students in girls' schools. Among 2,238 subjects varying in age from 11 to 16 years they discovered 9 color defectives. The Stilling Plates were used by daylight in the school rooms and all doubtful cases were taken to a clinic where further tests were made with the Stilling Plates, the Holmgren Wools and

the Nagel Anomaloscope. The heredity of six of the color defectives was carefully worked out and so far as possible the living members of their families were tested. The authors present complete genealogies and anomaloscope readings for 17 color defectives in these 6 families. In two families it seems clear that the mother must have been a "conductor" of color-blindness, and in no case is there testimony adverse to Horner's law, that color-blindness is transmitted from fathers through unaffected mothers to grandsons. Both deuteranopes and protanopes were identified but the hereditary relationship of the two types is not clear. Schiöts reported that so far as he had tested he had always found the same type of color-blindness in a family. Wölfflin (**119**) gives a genealogy in which deuteranopes and deuteranomalous trichromates appear in succeeding generations. Hess (**58**) finds three methods of inheritance and cites instances: the same defect in successive generations (father and daughter both green-blind, with normal sensitivity to blue and yellow); the same type of defect, but in different degrees, among siblings (two green-blind brothers, one with normal, the other with supernormal sensitivity to blue and yellow); different degrees of a defect in different generations (red-sighted father with two equally red-sighted daughters and a green-blind son all having normal sensitivity to blue and yellow). Hess says he has seen no family in which there were both red-blind and green-blind cases, nor any descendants of red-sighted who were green-sighted or red-blind. He feels particularly sure of his cases because of the "objective" evidence obtained by his Differential Pupilloskop. His families, however, do not fit the hereditary pattern now commonly assumed. Döderlein (**18**) gives an excellent review of the literature to date. He suggests that the particular difficulties mentioned by Hess—that defects seem to descend from father to son and that there are differences in degree in succeeding generations—may be overcome by a more extended study of these families, as it is possible that the inheritance may have come through mothers who were conductors, and not immediately from the defective fathers. In his own genealogy he finds a red-sighted father passing the defect to a daughter, while the wife who was descended from a family showing green-blindness passed this type of defect to her sons. In view of the unsatisfactory methods often employed and the incomplete genealogical evidence in many families reported, Döderlein undertakes to advance the science by a complete study of the Döderlein and Schoen families. These two families have intermarried and in both strains there are color

defects—red-blindness and red-sightedness. Some of the subjects knew of their defects only after extended experimentation. All members of the III, IV and V generations were tested by Döderlein or his colleagues except two cases who were deceased and judged to be color-blind on the testimony of near relations. Döderlein himself used the Hess Tunnel Modell and Differential Pupilloskop, the Nagel Anomaloscope, rotating discs, a perimeter and a solar spectrum with 40 members of the two families. He suggests that since the study of human heredity is so slow we might accelerate matters through a study of animals. It is easy to recognize types by the use of the Hess Pupilloskop and to obtain objective results with animals as well as with human beings. We might well test a large number of hens and monkeys and after discovering color defects like those found in human beings, the appearance of these defects among the progeny of controlled breeding might well solve the problem for human beings.

The heredity of total color-blindness also has been studied recently: Wernicke's (**115**) two cases were brothers; Velter's (**107**) two cases were a brother and a sister; Waardenburg's (**114**) two cases were a brother and sister, the children of cousins. Waardenburg appeals to physicians to accumulate data on the heredity of total color-blindness. Vogt (**112**) says that total color-blindness is supposed to be very rare in Europe, but that this scarcity may be more apparent than real. He found three cases during the examination of 4,000 children in the Basle schools. The only previous cases reported in Switzerland were three found by Pflüger in 1898 in a Grundelwald family of ten members. He thinks cases may have been overlooked because poor vision is the primary defect and oculists may not have tested their cases for color sensitivity. Vogt's three cases belong to three separate families having no relationship to each other, and no other cases could be discovered in any of these families. Vogt thinks total color-blindness is recessive and that the consanguinity of parents plays an important rôle in its production. Kleinguti (**69**) reports a careful study of a family in which 4 out of 7 children have retinitis pigmentosa, nystagmus and total color-blindness. In this family, as in one of the three reported by Vogt, there was consanguinity of parents and Kleinguti concludes that both retinitis pigmentosa and total color-blindness are recessive characters which appear only when inherited from both parents. He opposes the recent suggestion of Hess that protanopes represent a transition stage between deuteranopes and the totally color-blind since

protanopes show none of the most characteristic defects of the totally color-blind—foveal blindness, nystagmus or light dread. They do approximate the totally color-blind in pupillimotor values and in the shift of brightness to the blue-green region.

Recent surveys tend to support the common claim that partial color-blindness is about ten times as frequent among men as it is among women, though there is considerable difference of opinion as to the absolute frequency of each, depending upon the tests used and the method of classification employed. Schiötz (**95**) found 10 per cent among 300 males and just under 1 per cent among 2,200 females tested. Vogt and Kleinguti (**113**) found only 0.4 per cent among 2,200 girls, and put the frequency for men at 4 per cent. Franke (**32**) found 8.5 per cent among 750 men and Taylor (**100**) found 5.4 per cent among the 1,000 men tested in N. S. Wales. Collins (**12**) found only .6 per cent of girls and 1.9 per cent of boys in a survey of over 1,000 Edinburgh school children including about equal numbers of boys and girls from 9 to 12 years of age.

References

1. Allen, F., Persistence of Vision and the Primary Color Sensations. *Am. J. Physiol. Optics,* 1920, **1**, 94–134.
2. Atkinson, E. L., Snow-blindness: its Causes, Effects, Prevention and Treatment. *Brit. J. Ophth.,* 1921, **5**, 49–54.
3. Bender, H., Untersuchungen am Lummer-Pringsheimschen Spektral-flicker-photometer. *Zsch. f. Sinnesphysiol.,* 1918, **50**, 1–20.
4. Boehmig, Ueber das zentrale Farbenunterscheidungsvermögen nach körperlichen Anstrengungen. *Münch. med. Woch.,* 1922, **69**, 962.
5. Boström, C. G., Farbensinnfragen. *8 Jahresversammlung der Schwedischen Augenärztlichen Vereins,* Stockholm, 1915.
6. Burch., G. L., A Confusion-test for Color Blindness. *Proc. Roy. Soc.,* 1912, **B85**, 81–83.
7. Charles, J. W., Adler's Pencil-test for Color-blindness. *Am. J. Oph.,* 1922, **5**, 737.
8. Clark, J. H., Ishihara's Test for Color-blindness. *Am. J. Physiol. Optics,* 1924, **5**, 269–276.
9. Cohn, H., *Täfelchen zur Prüfung feinen Farbensinns mit Benutzung des Meyerschen florcontrastes.* Berlin: 1905, Coblentz, 5th ed.
10. ———, Worsted Test. (Letters worked in worsted upon a background of a confusion color.)
11. Cole, L. J., An early Family-history of Color-blindness. *J. of Hered.,* 1919, **10**, 372–374.
12. Collins, M., *Colour-Blindness.* New York: 1925, Harcourt, Brace.
13. Collins, M., Bradley Paper Test. (90 samples of Bradley paper in standard hues, tints and shades, and 10 greys.)

14. Cowdrick, M., and Winfield, M. Adjustment of the Hering Color-blindness Apparatus. *Am. J. Psych.*, 1919, **30**, 418–422.
15. Crosland, H. R., A Case of Achromasia with Complications. *Am. J. Psych.*, 1924, **35**, 593–601.
16. Daae, A., *Die Farbenblindheit und deren Erkennung.* Berlin: Dorffel.
17. Davenport, C. H., The Problem of Incidence in Color-blindness. *Amer. Nat.*, 1924, **58**, 447–456.
18. Döderlein, G., Ueber die Vererbung von Farbensinnsstörungen. *Arch. f. Augenhk.*, 1922, **90**, 43–66.
19. Donders, F. C., Worsted Test. (Worsted of one color wound about a small wooden cylinder, with a confusion color wound over this to form the rays of a star.)
20. Edridge-Green, F. W., *Physiology of Vision.* London: 1920, Bell.
21. ———. Classification Test. (Test wools of orange, violet, red and blue-green, with 180 confusion colors.)
22. ———. Pocket Test. (19 cards with holes through which single threads of wool or silk are woven.)
23. ———. Card Test for Color-blindness. London: G. Bell and Sons, Ltd. $5.
24. ———. Lantern for Testing Color-Vision. New York: E. B. Meyrowitz. $85.
25. ———. Temporary Color-blindness. *Lancet*, 1924, **206**, 801–802.
26. Eliot, R. H., Quinine Poisoning: Its Ocular Lesions and Visual Disturbances. *Am. J. Ophth.*, 1918, **1**, 547–567.
27. Engelking, E., Ueber den methodischen Wert physiologischer Perimeterobjekte. *Arch. f. Ophth.*, 1921, **104**, 75–90.
28. Engelking, E., and Eckstein, A., Neue Farbenobjekte für die klinische Perimetrie. *Kl. M. f. Augenhk.*, 1920, **64**, 664–670.
29. ——— and ———. *Peripheriegleiche und invariable Perimeterobjekte zur Vereinfachung und Verbesserung der Farbenperimetrie.* Freiburg: 1920, Speyer und Kärner.
30. Engelking, E., Vergleichende Untersuchungen ueber die Pupillenreaction bei der angeborenen totalen Farbenblindheit. *Kl. M. f. Augenhk.*, 1922, **69**, 177–188.
31. ———. Ueber den Stereowert und Zeitdifferenzwert verschiedenfarbiger Lichter und die relative Empfindungszeit der Stäbchen und Zapfen bei den angeborenen Störungen des Farbensinnes. *Kl. M. f. Augenhk.*, 1924, **73**, 1–28.
32. Franke, E., Ueber einige Ergebnisse vergleichender Farbensinnprüfungen. *Arch. f. Augenhk.*, 1917, **82**, 1–14.
33. Ferree, C. E., and Rand, G., An Apparatus for Testing Light and Color Sense. *Am. J. Ophth.*, 1920, **3**, 812–814.
34. Gibson, C. R., An Exhibition of Some Experiences in Color-blindness. *Proc. Phys. Soc.*, 1919, **31**, 79–80.
35. Gildemeister, M., und Deiter, W., Ueber die Erlernung von Farbenungleichungen. *Arch. f. Ophth.*, 1922, **107**, 26–29.
36. Göthlin, G. F., Polarisationsanomaloskopet, en apparat för diagnostisk undersökning of färgsinnet. *Svenska Lakarsallskopets Handl.*, 1916.

37. Grill, C., Untersuchungen ueber simultanen Farbenkontrast bei einem anomal-trichromatischen Sehorgan. *Upsala Lakeref Fordhande,* 1922, **23**, 367–375.
38. Groethuysen, —., Ueber die Beziehungen zwischen motorischer und optischer Unterschiedsempfindlichkeit des Auges. *Arch. f. Augenhk.,* 1920, **86**, 20–29; 1921, **87**, 152–188; **88**, 83–115.
39. Grow, E. J., Remarks on Color-blindness, together with some of the objections found with a few of the Color-perception Tests now in use. *U. S. Naval Med. Bull.,* 1921, **15**, 10–20.
40. Guttmann, A., Die Lokalization des Farbenkontrastes beim anomalen Trichromaten. *Zsch. f. Sinnesphysiol.,* 1920, **51**, 159–164.
41. ———. Ueber Abweichungen im zeitlichen Ablauf der Nachbilder zwei verscheidenen Typen des Farbensinns. *Zsch. f. Sinnesphysiol.,* 1920, **51**, 165–175.
42. Hegner, C. A., Zur Methodik der Sehprüfung. *Arch. f. Augenhk.,* 1921, **88**, 42–57.
43. Helmbold, Zur Prüfung des Farbensinnes mit Pigmentfarben. *Arch. f. Augenhk.,* 1913, **75**, 381–383.
44. ———. *Eine Methode der Farbensinnprüfung mit variablen Pigment-Farbengleichungen auf drehbaren Scheiben.* Weisbaden: J. F. Bergmann.
45. Hering, E., Zur Diagnostik der Farbenblindheit. *Arch. f. Ophth.,* 1890, **36**, 217–233.
46. ———. Color-Blindness Apparatus. Göttingen: Spindler und Hoyer.
47. Hess, C. von, Die Farbensinnprüfung des Bahn und Schiffpersonals und die Notwendigkeit ihrer Neugestattung. *Med. Klin.,* 1920, No. 50.
48. ———. Einige Methoden zur messenden Untersuchung von Farbensinnstörungen. *Zsch. f. Augenhk.,* 1920, **43**, 28–46.
49. ———. Einfache Apparate zur Untersuchung des Farbensinnes und seiner Störungen. *Arch. f. Augenhk.,* 1920, **86**, 222–246.
50. ———. Das Differential-Pupilloskop. *Arch. f. Augenhk.,* 1916, **80**, 22–31.
51. ———. Farbensinnprüfer. Berlin: Lautenschläger. Modell für die Praxis, Mk. 68; Klinisches Modell, Mk. 176; Tunnel Modell, Mk. 230; Differential-Pupilloskop, Mk. 483.
52. ———. Die Rotgrünblindheiten. *Arch. f. d. ges. Physiol.,* 1920, **185**, 147–164.
53. ———. Die angeborenen Farbensinnstörungen und das Farbengesichtsfeld. *Arch. f. Augenhk.,* 1920, **86**, 317–335.
54. ———. Die relative Rothsichtigkeit und Grünsichtigkeit. *Arch. f. Ophth.,* 1921, **105**, 137–153.
55. ———. Das Farbensehen der Anomalen. *Arch. f. Augenhk.,* 1922, **91**, 133–146.
56. ———. Zwischenstufen zwischen partieller und totaler Farbenblindheit. *Arch. neérl. de physiol.,* 1922, **7**, 179–184.
57. Hess, C. von, Methoden zur Untersuchung des Licht- und Farbensinnes sowie des Pupillenspieles. Abt. V, Teil 6 in der *Handbuch der biologischen Arbeitsmethoden.* Berlin: 1922, Urban und Schwarzenberg.
58. ———. Farbenlehre. *Ergebnisse der Physiologie,* 1922, **20**, 1–107.
59. Hoffmann und Nussbaum, Ueber die makulare Dunkeladaptation der total Farbenblinden. *Zsch. f. Biol.,* 1923, **78**, 251–258.

60. Holmgren, F., Wool Test. (Oldberg selection authorized by Holmgren.) Chicago: C. H. Stoelting Co.

61. Holth, S., Meine Dreiobjekte Probe für zentrales Farbenskotom auch bei Rotgrünblinden oder anderen Farbensinnabnormen. *Klin. M. f. Augenhk.*, 1921, **67**, 166–170.

62. ———. Farbenproben. Berlin: R. Wurach. Drei-Objekten-Farbenprobe auf Karton, Mk. 1.50; Drei-Objekten-Farbenstab, Mk. 3; Perimeterwürfel, 5, 10 und 15 mm. Durchmesser Das Stück, Mk. 2.50.

63. Hunt, R. H., Color Test Not Reliable as a Mental Test. *U. S. Naval Med. Bull.*, 1924, **21**, 74–76.

64. Ishihara, S., *Tafeln zur Prüfung des Farbensinnes.* Tokio: Kanehara and Co. Chicago: C. H. Stoelting.

65. Jennings, J. E., Clinical and Office Methods of Testing for Color-blindness. *Am. J. Physiol. Opt.*, 1920, **1**, 77–93.

66. ———. Second Edition of the Jennings Self-Recording Test for Color-blindness: An Estimate of the Value of the Test. *Am. J. Ophth.*, 1922, **5**, 270–273.

67. ———. Self-recording Test for Color-blindness. Philadelphia; McAllister and Co., 2d Ed., 1922.

68. Kirschmann, A., Gläser für Farbenblinde. *Deut. opt. Woch.*, 1915, No. 43, 609.

69. Kleinguti, R., Farbensinnstörung bei Retinitis pigmentosa und totale Farbenblindheit. *Schweiz. med. Woch.*, 1923, **53**, 910–912.

70. Köllner, H., Ueber Ursache des sogenannte gesteigerten Kontrastes der Farbenschwachen. *Arch. f. Augenhk.*, 1916, **81**, 37–55.

71. ———. Zur Analys der Rayleigh-Gleichung der anomalen Trichromaten. *Arch. f. Augenhk.*, 1919, **84**, 177–195.

72. ———. Fortschritte in der Erkenntnis der Farbensinnstörungen. *Deut. med. Woch.*, 1924, **50**, 228–238.

73. Kawakami, R., Heredity of Color-blindness. *Jap. Med. World*, 1922, **2**, 262–270.

74. Kries, J. von, Zur physiologischen Farbenlehre. *Kl. M. f. Augenhk.*, 1923, **70**, 577–629.

75. Lohmann, W., Ueber die nach Schneeblindheit beobachtete Rotgrünblindheit. *Arch. f. Augenhk.*, 1915, **79**, 35–38.

76. ———. Ueber das Verhältnis der Rayleighgleichung zum gesteigerten Farbenkontrast bei den anomalen Trichromaten. *Arch. f. Augenhk.*, 1915, **79**, 135–141.

77. ———. Ueber das Wesen und die Bedeutung der gestiegerten Farbenkontrastes bei den anomalen Trichromaten. *Arch. f. Augenhk.*, 1917, **82**, 104–111.

78. Magnus, H., Wool Test. (Subject selects wools to match spectral colors.)

79. Malling, B., Color Sense. *Am. J. Ophth.*, 1919, **1**, 362–370.

80. Nagel, W. A., *Tafeln zur Untersuchung des Farbenunterscheidungsvermögens.* Wiesbaden: J. F. Bergmann. 9th ed.

81. ———. Anomaloskop. Model I, Mk. 551; Model II, Mk. 787. Berlin: Schmidt und Haensch.

82. Oliver, C. A. Holmgren Wool Test. (Five test skeins, five pure skeins shaded and eighteen confusion skeins each of which represents a two to one mixture of two of the test colors.) New York: E. B. Meyrowitz.
83. ———. Oliver-Abney Pellet Test for Central Scotoma. (Seventeen colored ivory balls in tray with cover.) New York: E. B. Meyrowitz.
84. Oloff, H., Ueber Farbensinnstörungen in der Marine. *Kl. M. f. Augenhk.*, 1918, **61**, 337–338.
85. ———. Beiträge zur Prüfung angeborener Farbensinnstörungen. *Med. Klin.*, 1919, **15**, 233–236.
86. ———. Die Untersuchung angeborener Farbensinnstörungen. *Kl. M. f. Augenhk.*, 1924, **72**, 603–628.
87. Podesta, H., Die Bedeutung der Farbensinnstörungen für den Seemansberuf und ihre Erkennung. *Ann. d. Hydrogr. u. Maritim-Meterol.*, 1916, **44**, 1–16.
88. ———. *Wandtafeln zur Prüfung des Farbensinnes und Erkennung der Farbenstörungen.* Hamburg: 1916, D. Friedericksen. Mk. 15.
89. Reichert, *Ueber einseitige Farbensinn-Anomalien.* Freiburg: 1916.
90. Robinson, F. R., A Case of Color-blindness to Yellow and Blue. *Am. J. Psych.*, 1923, **34**, 157–184.
91. Roaf, H. E., Observations on Color-blindness. *Jour. Physiol.*, 1923, **57**, 27–35.
92. ———. A Simple Device Whereby Some Color-blind Persons Can Recognize Color Differences. *Jour. Physiol.*, 1924, **59**, 29–32.
93. Rochat, G. F., Apparat zur Diagnose der Farbensinnsanomalien. *Niederl. ophth. Ges.*, 1914, **14**, 6–10.
94. Roenne, H., Ueber angeborene unvollstandige Dichromasie mit angeknüpften therapeutischen Bemerkungen über die Verhaltnisse dieses Zustandes zur anomalen Trichromasie. *Kl. M. f. Augenhk.*, 1917, **58**, 41–58.
95. Schiötz, I., Color-blind Females: the Inheritance of Color-blindness in Man. *Brit. J. Ophth.*, 1920, **4**, 345–359, 393–403.
96. ———. Rotgrünblindheit als Erbeigenschaft. *Kl. M. f. Augenhk.*, 1922, **68**, 498–526.
97. Seydel, —., Die Helmboldschen Farbenprüfung-methode. *Vereinin. der Augenarzte Schlesiens u. Posen,* 1914, **27**, 6–10.
98. Stilling, J., *Pseudoisochromatische Tafeln zur Prüfung des Farbensinnes.* Leipzig: 1922, Thieme. 16th ed.
99. Sulina, A., Ueber den Farbensinn bei Kindern nebst Bemerkungen über die Untersuchungsmethoden. *Russ. ophth. J.*, 1923, **2**, No. 6.
100. Taylor, G. H., Color Testing. *Ophthal.*, 1915, **12**, 91–100.
101. ———. Color and Moral Sense. *Ophthal.*, 1915, 242–260.
102. ———. Color Testing and the Psychology of Color. *Am. J. Psych.*, 1924, **35**, 185–189.
103. Thomson, W., Lantern for Testing Color Vision. New York: E. B. Meyrowitz. $48.
104. ———. Stick of Color Worsteds, for Color Testing. (Forty numbered worsteds mounted on stick with cover.) New York: E. B. Meyrowitz.
105. Titchener, E. B., Laboratory Notes. *Am. J. Psych.*, 1914, **25**, 297.

106. Troland, L. T., Present Status of Visual Science. *Bull. Nat. Res. Council,* 1922, **5**, Part 2, No. 27.
107. Velter, E., Complete Color-blindness with Anomalies of the Macula. *Amer. J. Ophth.,* 1923, **6**, 935–940.
108. Verrey, A., L'examen de la perception colorée et nos administrations fédérales. *Rev. gén. d'ophth.,* 1923, 381–385.
109. Verrey, A., und Wölfflin, E., Die Farbensinnprüfung und unsere eidengenössischen Verwaltung. *Schweitz. Ophth. Ges.,* 1923.
110. Vierling, —, Vergleichende Untersuchungen über die Leistungen der Wichtigsten Pigmentproben. *Zsch. f. Bahn- u. Bahnkassenärzte,* 1913, **6**, No. 7.
111. Vogt, A., Ueber geschlechtgebundene Vererbung von Augenleiden. *Münch. med. Woch.,* 1919, **66**, 850.
112. ———. Cécité compéte pour les couleure aves presentation de trois cas. *Rev. gén. d'ophth.,* 1922, **36**, 312–315.
113. Vogt, A., und Kleinguti, R., Weitere Untersuchungen über die Entstehung der Rotgrünblindheit beim Weibe. *Arch. f. Rassen- und Gesellschbiol.,* 1923, **14**, 130–140.
114. Waarbenburg, P. J., Ein Fall von totalen Farbenblindheit. *Ned. Tijds. v. Geneesk.,* 1914.
115. Wernicke, O., Total Achromatopsia. *Am. J. Ophth.,* 1918, **1**, 365–367.
116. Westcott, —, Color Slide for Testing Color-blindness. Chicago: Central Scientific Co. $3.
117. Williams, —, Lantern for Testing Color Vision. New York: E. B. Meyrowitz. $65.
118. Wirth, W., Beiträge zur psychophysischen Anthropologie. I. Anomalien der Gesichtsfarbe als Begleiterscheinungen der Farbenblindheit. *Arch. f. d. ges. Psychol.,* 1919, **39**, 289–298.
119. Wölfflin, E., Ueber Beeinflussung des Farbensinnes bei anomalen Trichromaten. *Kl. M. f. Augenhk.,* 1922, **69**, 205–212.
120. ———. Ueber das Vererbungsgesetz der anomalen Trichromaten. *Arch. f. d. ges. Physiol.,* 1923, **201**, 214–219.
121. ———. Die Farbensinnprüfung. *Schweiz. Ophth. Ges.,* 1923.
122. ———. Ueben eine neue Methode zum Nachweis der Farbenüberempfindlichkeit. *Deut. Ophth. Ges.,* 1924.